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# USAGE-BASED INSURANCE OR THE IMPLICATIONS OF TAKING BIG BROTHER FOR A RIDE

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# Usage-based insurance or the implications of taking Big Brother for a ride

by

Devina Lakhtakia

A Major Research Paper

Submitted to the Faculty of Graduate Studies

through the Department of Economics

in Partial Fulfillment of the Requirements for

the Degree of Master of Arts at the

University of Windsor

Windsor, Ontario, Canada

2018

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USAGE-BASED INSURANCE OR THE IMPLICATIONS OF TAKING BIG  
BROTHER FOR A RIDE

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June 21, 2018

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# Abstract

The use of telematics in the automobile industry has been growing recently to resolve the problem of asymmetric information in the insurance market related to the identification of the type of a driver. This paper aims to study the impact of the introduction of usage-based insurance on the market participants taking into account the privacy costs associated with the installation of such a behaviour-monitoring device. We assume that UBI is offered as part of the contract to the agents and is voluntary to install. Our findings suggest that no matter how highly an agent values her privacy, there will always be some proportion of the low-type agents who register for UBI to receive full coverage at a higher premium. Moreover, the high-types are weakly worse-off with the introduction of UBI as they pay a higher premium for full coverage. The results of our analysis imply that UBI is Pareto-improving if it allows the company to serve a new market, in which the low-types were not being served initially, else it might be welfare decreasing.

Keywords: Usage-based insurance, privacy costs, asymmetric information, welfare

JEL Classification: D62, D82, D86, G22

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# 1 Introduction

It is well known that the presence of asymmetric information about the type of agents in the insurance market distorts the contracts being offered to the agents. There are good drivers (low-types) who remain within speed limits, follow traffic regulations, etc. Bad drivers (high-types) drive unsafely and fail to adhere to traffic rules and regulations. It is not possible for an insurance company to determine whether a driver is a high or low-type when they offer the contract initially. The insurance company can at best determine the type of the agent by looking at her previous claims, age, city of residence, mileage, etc. However, claims might be underreported and mileage declared incorrectly. This means that the company cannot form an accurate judgement regarding the type of the driver, a problem that is referred as the ‘hidden-type’ model in the literature of information economics. Information asymmetry induces a high-type driver to try to pass as a low-type driver. According to the classic theory in information economics (Rothschild and Stiglitz, 1976), the low-types subsidise the high-types, who are offered full-coverage. The information asymmetry forces the insurance company to expose the low-types to some risk, by offering a policy which is cheaper but provides partial coverage. Hence, the insurance company needs to provide incentives such that the drivers self-select and opt for the policy designed for them according to their type.

Usage-based insurance (UBI) provides a solution to reduce the information asymmetry in the market. UBI is offered as an additional device to the agents, and they have an option to install it or not. If the agent agrees to sign up for UBI, a small telematic device is plugged in their car, which transmits information about their driving behaviour to the insurance company. Information on miles driven, braking, speed, etc. is collected and transmitted to the company. The insurance company then analyses this information and assigns a driving score to the driver. The premiums are calculated

according to the driving behaviour of the individual as compared to the traditional premium calculations, which were based on the information reported by the driver.

The concept of usage-based insurance is not entirely new. The black-boxes for cars were introduced in 2003, and due to the high cost of the technology at that time, information was collected in real-time but recovered only in case of an accident. Given the high cost it was mainly targeted to young-drivers who were presumed to be the high-types.<sup>1</sup> With technology advancements, the cost of producing behaviour-monitoring devices has decreased and UBI devices now transmit information in real-time. It is now a common trend for companies to offer different types of usage-based insurance, for example, pay-as-you-drive (PAYD), pay-as-you-speed (PAYS), pay-how-you-drive (PHYD), etc. Pay-as-you-drive is based on the miles driven by the agent. Pay-as-you-speed rewards drivers for maintaining speed limits while driving. Pay-how-you-drive provides incentives for drivers to drive more carefully and avoid sudden acceleration, excessive braking, sharp turning, etc. The market for UBI has grown by 26 % worldwide in 2017, the major growth being accounted for in the United States.<sup>2</sup> If a low-type driver registers for UBI, it can lead to a reduction in premium by about 25 %.<sup>3</sup> Even though that is a substantial reduction in premium for low-type drivers, it comes with a privacy cost. Once the driver installs the device in their car, the insurance company gains access to all whereabouts of the driver. The privacy costs arise from the disutility agents get from being monitored. Thus, some good drivers might not be interested in installing the device to protect their privacy even though it might lead them to receive a contract which is worse than previously offered.

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<sup>1</sup><https://www.insurancebusinessmag.com/ca/news/auto/ubi-company-targeting-under-24-market-in-ontario-46792.aspx>

<sup>2</sup><https://www.ptolemus.com/ubi-study/quarterly-ubi-dashboard/ubi-dashboard-update-jan-18/>

<sup>3</sup><http://www.cbc.ca/news/canada/sudbury/insurance-companies-use-black-box-technology-to-track-driving-habits-1.3187410>

The concept of UBI is not limited to the automobile market but extends to health insurance and other sectors. It is increasingly common for health insurance companies to offer smart-watches as trackers to determine the well-being and activity levels of the client. The premium is charged accordingly to the insured. Another example would be companies performing a credit-check for their potential new-hires, to determine whether they are good or bad risks to the company. Supposing that personal finance is a proxy for the type of the agent (good or bad employee), a credit check can reduce asymmetry between companies and their potential new hires.

Our aim is to study the effects of UBI on the contracts offered by an insurance company with market power, as well as on the profit and welfare levels, while taking privacy costs into account. Insurance companies market usage-based insurance as a scheme to reward low-type drivers, but we show that it is mostly a tool to extract a higher premium from the high-types once they are identified by the company after the introduction of UBI. It could be argued that UBI might lead a driver to change her behavior and become a safe driver but we focus on the hidden-type problem in our study.<sup>4</sup> UBI and black-boxes have been the subject of a few previous studies. A study by Arvidsson (2011) shows that the low-types and the high-types get full coverage at their actuarially fair rates after low-types register for UBI. However, to obtain analytical results it assumes that the insurance company provides full insurance to both types of drivers. By opposition we fully consider the incentive compatibility constraints which lead to low-types receiving partial coverage, and additionally differentiate agents according to their privacy costs. Several studies (Hultkrantz et al. (2012), Stigson et al. (2014), Agerholm et al. (2008), Litman (2005)) examine the impact of introducing UBI as a tool to change the driving behaviour of the agent, thereby reducing the moral hazard problem. Another study by Fan et al. (2016) aims

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<sup>4</sup><http://www.cbc.ca/news/canada/british-columbia/usage-based-insurance-ubi-car-insurance-big-brother-1.4193862>

at measuring privacy costs and the gap between the willingness to share data and the importance of that data in UBI. Closest to our analysis is the model proposed by Filipova-Neumann and Welzel (2010) which studies the impact of offering black-boxes as an additional contract for drivers. The insurance company offers the agents to install black-boxes which would record their driving behaviour. As opposed to UBI, the company would gain access to the information only when an accident occurs. Thus, in opposition to how we model UBI, all users who register for a black-box initially pay the same premium, and the type is discovered only if an accident occurs. It is only then the company observes the type of the driver. If the driver is low-type, the company offers them a full coverage, else they only receive partial coverage. Contrary to what happens with UBI (and in our model), high-type agents are able to masquerade as low-types as long as an accident does not occur. They study the impacts for both competitive and monopoly markets, and generally find that the black-boxes are welfare improving, even with privacy costs, modelled as a fraction of agents having the same disutility for sharing their information. As we do for UBI, they find that black-boxes are Pareto-improving if it allows to offer coverage to clients unserved before.

The other major difference in our analysis is how we model privacy costs, with these being uniformly distributed in an interval. That allows for more subtle and realistic results in which the company optimally chooses the proportion of agents who register for UBI, and in which we never have that nobody registers and only obtain that all low-types register if privacy costs are extremely low. We find that the device might lead to a loss in overall welfare. The low-types who register get full insurance at higher premiums and the device has no effect on the welfare of low-types who do not register due to privacy concerns. The high-types receive the same full coverage but at a higher premium. An exception is when the low-types were not being served by the company earlier.

The rest of the paper is organized as follows: Section 2 presents the general setting of the model. Section 3 provides the results once UBI is introduced, Section 4 analyses welfare effects on market participants and discusses policy implications. Section 5 concludes and lists some extensions.

## 2 The Model

There are two types of risk-averse drivers in the market, high-types ( $h$ ) and low-types ( $l$ ), with identical von Neumann-Morgenstern utility functions, a single insurance company in a monopoly position. Low-type agents drive more carefully, keep within speed limits and pay more attention to traffic rules. On the other hand, high-type drivers may engage in speeding, not following traffic rules, etc. Both have the same initial wealth,  $W$ , but have different probabilities of incurring an accident. If they incur an accident, they suffer a loss,  $L$ ,<sup>5</sup> where  $0 < L < W$ . The utility function we assume for the agents to study the impact of usage-based insurance is  $\sqrt{y}$ , where  $y$  is income. This implies that both agents are risk-averse and hence would consider buying an insurance to compensate for their loss. The probability of accident for a low-type driver is  $\alpha$ , while for a high-type it is  $\delta$ . The high-type drivers are more prone to having an accident, hence  $0 < \alpha < \delta$ . If the agent buys insurance the compensation and premium depend on the contract signed with the insurance company. There are two possible scenarios. One in which there is no accident, and in that case, the agent pays the premium but does not receive any benefit. In case there is an accident, the agent receives a payment from the insurance company as compensation.

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<sup>5</sup> $L$  is not limited to the value of the car, and can include medical expenses and liabilities for the damage caused.

Due to information asymmetry, the insurance company cannot distinguish the type of driver, but can form an expectation regarding the proportion of each type. The total number of potential clients is normalised to 1, and a proportion  $\mu$  of the population is high-type, with  $0 < \mu < 1$ . The policy  $(x_l, p_l)$  is offered to low-types and  $(x_h, p_h)$  is offered to high-types, where  $x_i$  is the coverage offered and  $p_i$  is the premium the agent of type  $i$  pays. Since installing the device in a driver's car will allow the company to monitor them, there is a privacy cost,  $a_i$ , associated with the installation of the device, which varies agent to agent. It is assumed that there is no correlation between the type of the agent and her privacy costs. The privacy costs are uniformly distributed in the interval  $[0, A]$  where  $A$  represents the maximum amount at which an agent values her privacy and summarizes the importance of privacy cost in the market. To provide incentives to low-type drivers, the insurance company offers a rebate,  $R$ , if they choose to install the device.

We can write the utility for the low-type agent without insurance as:

$$U_l^{NI} = \alpha\sqrt{W - L} + (1 - \alpha)\sqrt{W}.$$

and for the high-type agents as:

$$U_h^{NI} = \delta\sqrt{W - L} + (1 - \delta)\sqrt{W}.$$

We define,  $p_i^{FB}$ , as the premium agent  $i$  pays if offered a first-best contract which provides full coverage to the agent. Mathematically, we can find:

$$p_i^{FB} \text{ s.t. } \sqrt{W - p_i^{FB}} = U_i^{NI}.$$

If the low-type agent buys the insurance without signing up for UBI then her utility is:

$$\alpha\sqrt{W - L + x_l - p_l} + (1 - \alpha)\sqrt{W - p_l}.$$

However, if the low-type agent buys insurance with UBI, her utility then becomes:

$$\alpha\sqrt{W - L + x_l - p_l + R - a_i} + (1 - \alpha)\sqrt{W - p_l + R - a_i}.$$

Similarly we can write the utility for high-type agents.

We can represent our problem in a game-tree with two stages.

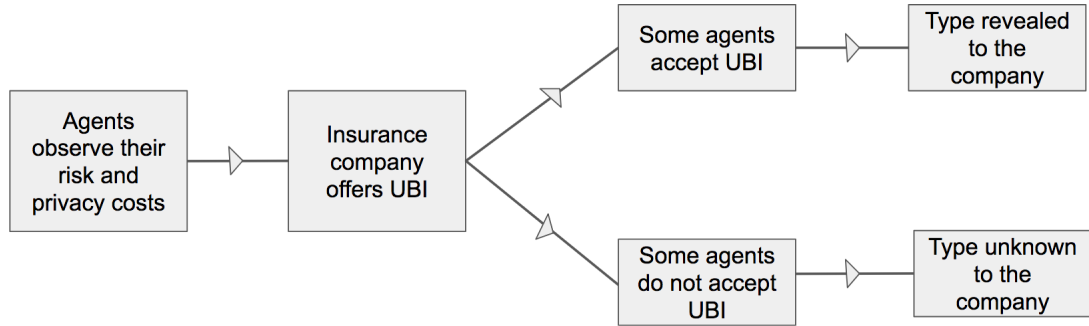


Figure 1: Game representation for UBI

In the first-stage low-types decide to register for UBI or not depending on their privacy costs,  $a_i$ , and the company offers contracts with UBI, which the agents either accept or refuse. After observing who has registered, the company offers contracts to the remaining agents without UBI.



### 3 Results

The results from our analyses of the impact of the introduction of UBI are presented below. We first examine the optimal contracts offered to the agents who do not register for UBI and to those agents that did register. We then examine how the agents decide to register or not, before examining how the rebate for using UBI is chosen.

#### 3.1 Contracts for agents who do not register

Once a proportion  $\beta$  of low-types have registered, the insurance company knows that a proportion  $\theta$  are high-types among the remaining population of drivers, which now consists of the high-type drivers and the low-type drivers who do not register. In order for both types to buy insurance, the participation constraint for low-types should be binding, and to avoid high-types to benefit by mimicking low-type agents, the incentive compatibility constraint for high-types should be binding. The insurance company as a monopolist wants to maximise its profits. In order for both types to buy insurance, the participation constraint for low-types should be binding, and to avoid high-types to benefit by mimicking low-type agents, the incentive compatibility constraint for high-types should be binding. From classic theory on information economics we know that the high-type are always fully insured,  $x_h^{SB} = L$  (Atkinson and Stiglitz, 1976). The insurance company offers low-types a contract  $(x_l^{SB}, p_l^{SB})$  and the high-types a contract  $(x_h^{SB}, p_h^{SB})$  such that the participation constraint of the low-types and the incentive compatibility constraint of the high-types are binding.

Mathematically, the participation constraint of the low-type is:

$$\alpha\sqrt{W - p_l^{SB} + x_l^{SB} - L} + (1 - \alpha)\sqrt{W - p_l^{SB}} \geq U_l^{NI}.$$

where the RHS represents the utility for the low-type agent without an insurance contract, and the LHS represents the utility of the agent if she buys insurance. Since this constraint is binding, we can solve for  $x_l^{SB}(p_l^{SB})$ . The incentive compatibility constraint of the high-type agent is:

$$\delta\sqrt{W - p_h^{SB} + x_h^{SB} - L} + (1 - \delta)\sqrt{W - p_h^{SB}} \geq \delta\sqrt{W - p_l^{SB} + x_l^{SB} - L} + (1 - \delta)\sqrt{W - p_l^{SB}}.$$

The incentive compatibility constraint implies that the high-types derive a higher utility from the contract designed for them (LHS) than that from the contract designed for the low-types (RHS). The fulfillment of this condition would lead to the high-types self-selecting the contract designed for them. Using the fact that  $x_h^{SB} = L$ , we can write

$$\sqrt{W - p_h^{SB}} \geq \delta\sqrt{W - p_l^{SB} + x_l^{SB}(p_l^{SB}) - L} + (1 - \delta)\sqrt{W - p_l^{SB}}.$$

Since it is also binding we can solve for  $p_h^{SB}(p_l^{SB})$ .

The profit function can then be written and maximised as a function of  $p_l^{SB}$ :

$$\max_{p_l^{SB}} \Pi = \theta(p_h^{SB}(p_l^{SB}) - \delta L) + (1 - \theta)(p_l^{SB} - \alpha x_l(p_l^{SB})).$$

Since this problem cannot be solved analytically, we provide a numerical solution. We define initial parameters as:  $W = 200000$ ,  $L = 100000$ ,  $\alpha = 0.05$ ,  $\delta = 0.08$ ,  $\mu = 0.20$  and  $A = 1000$ . The contracts offered without UBI are then  $x_l^{SB} = 43283.56$ ,  $p_l^{SB} = 2751.36$ ,  $x_h^{SB} = 100000$ , and  $p_h^{SB} = 7641.63$ . The profit for the company without UBI is 398.07.

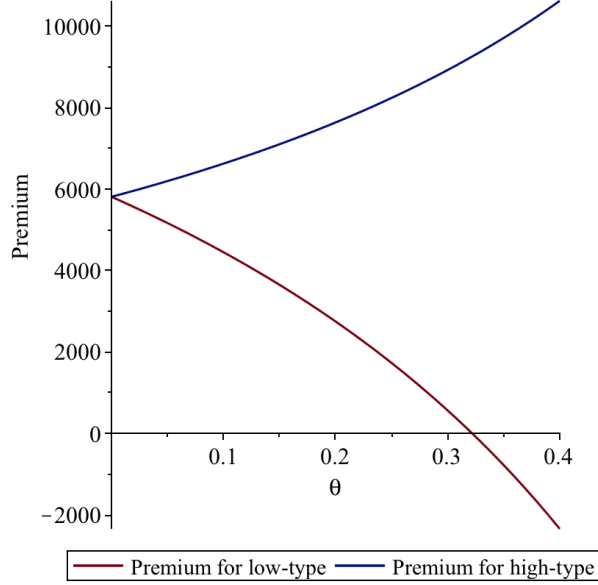


Figure 2: Premium for high and low-types

Figure 2 depicts the premiums charged in the second-stage to the high-types and the low-types who do not register, as a function of  $\theta$ , the proportion of high-types. The premium for the low-types falls as the proportion of high-types rises in the market, as it becomes more profitable to serve the high-types. The insurance company charges higher premiums to the high-types. The contract offered to the low-types who did not register worsens as the company decreases their coverage and the premium charged (Figure 3). While in the graph  $x_l^{SB}, p_l^{SB} < 0$  for  $\theta \geq 0.32$ , the company cannot offer negative coverage and premiums, it instead stops serving the low-types ( $p_l^{SB} = x_l^{SB} = 0$ ). Since serving the low-types limits how much we can extract from high-types, as the proportion of high-types increases in the market, we reach a point where the low-types are abandoned. We call  $\bar{\theta}$  such proportion of high-types. When we reach such a point where the low-types are unserved, we say that the market for low-types has collapsed.

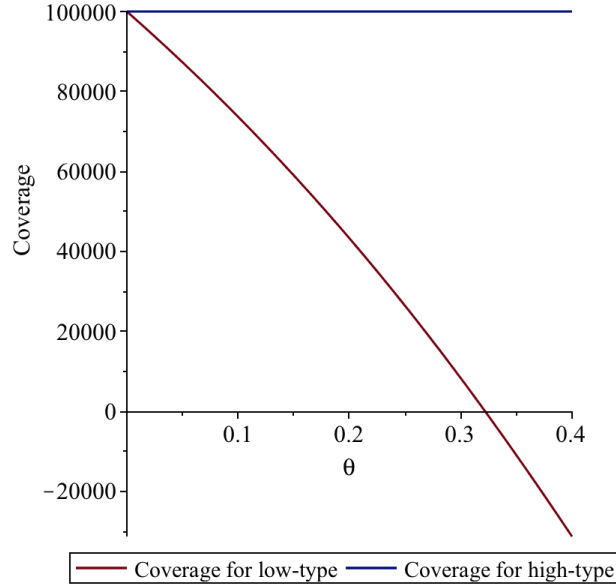


Figure 3: Coverage for high and low-types

### 3.2 Contracts for agents who register

As seen in the previous subsection, high-types enjoy an information rent, and the company would have to leave them with as much utility to convince them to install UBI. Additionally, the insurance company would also have to compensate them for their privacy cost, and offering this would be more costly to the firm than a contract without UBI. Hence, the policy offered to the high-type agents in case they register for UBI is  $(x_h^{FB}, p_h^{FB})$ , where  $p_h^{FB}$  is the premium charged to the high-types in a first-best contract. This condition would prohibit the high-types to sign up for UBI. As for the low-types the insurance company then knows their type and offers them full coverage  $(x_l^{FB}, p_l^{FB} - R)$ , with a rebate compared to the first-best contract to cover privacy costs. Given that the low-types receive partial coverage without UBI, there is an opportunity to increase profits for the company by offering UBI.

### 3.3 Decision to accept or not

The agents observe their privacy costs and decide whether to register for UBI or not. The rebate for installing the device is paid after the company observes their type. If the low-types decide to register, the utility they receive is:

$$\sqrt{W - p_i^{FB} - a_i + R}$$

while it is  $U_i^{NI}$  if she does not register. Since  $U_i^{NI} = \sqrt{W - p_i^{FB}}$ , the low-type who have  $a_i \leq R$  will sign up for UBI and those who value their privacy more will not.

Graphically, we have the following in which the low-types will decide whether to register for UBI or not taking their privacy costs in consideration.

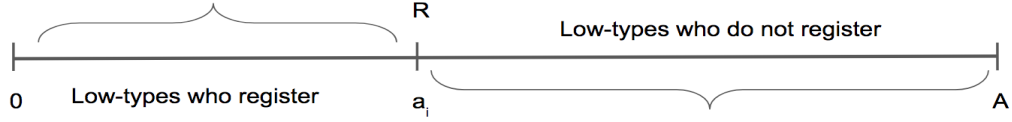


Figure 4: Low-types decide whether to register

If the high-types register for the device they would reveal their type to the insurance company and it will not provide them any rebates. Hence, the high-type agents will have to pay for their privacy costs. The utility for high-types from registering from UBI can be expressed as:

$$\sqrt{W - p_h^{FB} - a_i} \leq U_h^{NI} \leq \sqrt{W - p_h^{SB}}.$$

Since, the high-types get a higher utility from the second-best contracts, they will not register for the device.

### 3.4 Choice of Rebate

The insurance company can control the number of low-types who will register for UBI, by setting the rebates it will offer. As seen in the previous subsection, the low-types who value their privacy less than the rebate offered by the company will register and the ones who value their privacy more will not. For a rebate  $R \geq 0$ , agents with  $a_i$  in  $[0, R]$  register, and then by the uniform distribution assumption,  $\beta = \frac{R}{A}$ . Knowing this, the insurance company can select the proportion  $\beta$  of low-types who register by choosing  $R = \beta A$ .

Then, the insurance company knows the proportion of low-types who registered, and can evaluate the proportion of high-types in the remaining population of drivers by:

$\theta = \frac{\mu}{\mu + (1-\beta)(1-\mu)}$ . By backward induction and defining  $\pi_l^{FB}$  and  $\pi_l^{SB}$  as the first-best and second-best profits respectively when selling to the low-types, the profit function for the company can now be written entirely as a function of  $\beta$ :

$$\max_{\beta} \Pi = \mu(p_h(\theta) - \delta L) + (1 - \beta)(1 - \mu)(p_l(\theta) - \alpha x_l(\theta)) + \beta(1 - \mu)[\pi_l^{FB} - \beta A].$$

We define  $\beta^*$ , as the proportion of registrations required to maximise the profit for the company.

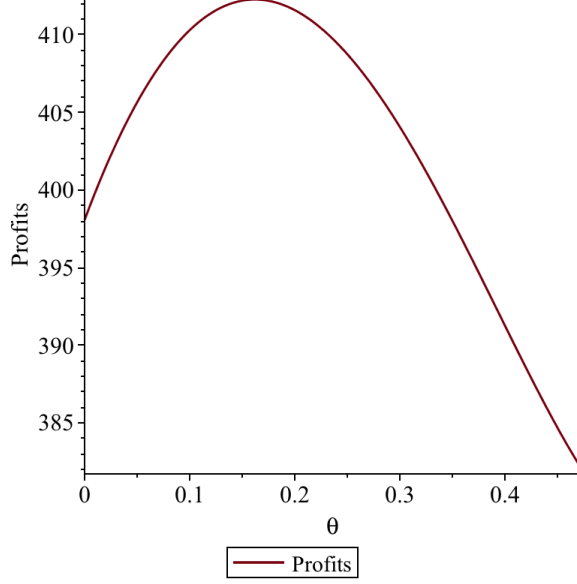


Figure 5: Optimal value of  $\beta$

Again we solve numerically for our example, and from Figure 5, we can see that the optimal number of registrations which maximize profit for the company is 0.163. The contracts offered at the optimal value of  $\beta$  are  $x_l = 33298.24$ ,  $p_l = 2155.37$ ,  $x_h = 100000$ ,  $p_h = 7994.36$ ,  $R = 163$ ,  $p_l^{FB} = 5814.36$  and  $x_l^{FB} = 100000$ . The profits after the introduction of UBI are \$412.27.

We define  $\bar{\beta}$  be the proportion of low-type registering that make the market collapse.<sup>6</sup> Even without having to solve analytically for  $\beta^*$ , we can proceed with the following results. If privacy costs,  $A$ , are very low, then all the low-type agents register for UBI ( $\beta^* = 1$ ). If  $A$  is low, the firm would make the market for the low-types collapse to maximise its profits ( $\beta^* > \bar{\beta}$ ). And if  $A$  is high, the company will continue to offer the second-best contracts for the low-types who do not register ( $0 < \beta^* < \bar{\beta}$ ). However, even if  $A$  is very high we have that some low-type agents always register for the device ( $\beta^* > 0$ ).

---

<sup>6</sup>i.e.  $\frac{\mu}{\mu + (1 - \bar{\beta})(1 - \mu)} = \bar{\theta}$  if  $\mu \leq \bar{\theta}$  and  $\bar{\beta} = 0$  if  $\mu \geq \bar{\theta}$

**Theorem 1** *i) If  $A \geq \frac{\pi_l^{FB}}{2\beta}$ , then  $0 < \beta^* \leq \bar{\beta}$*

*ii) If  $A \leq \frac{\pi_l^{FB}}{2}$ , then  $\beta^* = 1$*

*iii) If  $\frac{\pi_L^{FB}}{2} \leq A \leq \frac{\pi_L^{FB}}{2\beta}$  then  $\bar{\beta} \leq \beta^* \leq 1$ , with  $\beta^* = \frac{\pi_L^{FB}}{2A}$ .*

**Proof.** We first show that  $\beta^* \geq 0$ . The second-period profits are:

$$\Pi = \mu(p_h - \delta L) + (1 - \beta)(1 - \mu)(p_l - \alpha x_l) + \beta(1 - \mu)[\pi_l^{FB} - \beta A]. \quad (1)$$

Taking first-order conditions with respect to  $\beta$ , we get:

$$\begin{aligned} \frac{\partial \Pi}{\partial \beta} &= \mu \frac{\partial p_h}{\partial \beta} \cdot \frac{\partial p_l}{\partial \beta} + (1 - \mu)(1 - \beta) \left[ \frac{\partial p_l}{\partial \beta} - \alpha \frac{\partial x_l}{\partial p_l} \cdot \frac{\partial p_l}{\partial \beta} \right] - \\ &(1 - \mu)[p_l(\beta) - \alpha x_l] + (1 - \mu)[\pi_l^{FB} - \beta A] - \beta(1 - \mu)A = 0. \end{aligned}$$

We evaluate the first-order condition at  $\beta = 0$ :

$$\mu \frac{\partial p_h}{\partial p_l} \frac{\partial p_l}{\partial \beta} \Big|_{\beta=0} + (1 - \mu) \left[ \frac{\partial p_l}{\partial \beta} \Big|_{\beta=0} - \alpha \frac{\partial x_l}{\partial p_l} \frac{\partial p_l}{\partial \beta} \Big|_{\beta=0} \right] + (1 - \mu) \left[ \pi_l^{FB} - [p_l(0) - \alpha x_l(p_l(0))] \right]. \quad (2)$$

This is equivalent to:

$$\frac{\partial p_l}{\partial \beta} \Big|_{\beta=0} \left[ \mu \frac{\partial p_h}{\partial p_l} \Big|_{\beta=0} + (1 - \mu) \left( 1 - \alpha \frac{\partial x_l}{\partial p_l} \Big|_{\beta=0} \right) \right] + (1 - \mu) \left[ \pi_l^{FB} - \pi_l^{SB} \right]. \quad (3)$$

We have two cases :



1. The market has not collapsed, under which

$$\frac{\partial p_l}{\partial \beta} \neq 0. \quad (4)$$

Let  $\Pi^{SB} = \mu[p_h(p_l) - \delta L] + (1 - \mu)(p_l - \alpha x_l)$ . be the second-best profit when UBI is not an option.

Taking F.O.C. w.r.t.  $p_l$ :

$$\frac{\partial \Pi^{SB}}{\partial p_l} = \mu \frac{\partial p_h(p_l)}{\partial p_l} + (1 - \mu) - \alpha(1 - \mu) \frac{\partial x_l}{\partial p_l} = 0. \quad (5)$$

$$= \mu \frac{\partial p_h}{\partial p_l} + (1 - \mu) \left[ 1 - \alpha \frac{\partial x_l}{\partial p_l} \right] = 0. \quad (6)$$

Then using (6), we can simplify (3) into

$$\frac{\partial \Pi}{\partial \beta} = (1 - \mu)(\pi_l^{FB} - \pi_l^{SB}) > 0.$$

2. The market has collapsed, under which

$$\frac{\partial p_l}{\partial \beta} = 0. \quad (7)$$

and (3) simplifies to  $\frac{\partial \Pi}{\partial \beta} > 0$ .

Combining both cases, we conclude that  $\beta^* > 0$ .

We then distinguish three cases, depending if  $\beta^* \leq \bar{\beta}$ ,  $\bar{\beta} \leq \beta^* \leq 1$ , or  $\beta^* = 1$ . If  $\beta^* \geq \bar{\beta}$ , the first two parts of equation (1) are fixed w.r.t.  $\beta$ . So  $\frac{\partial \Pi}{\partial \beta} = \pi_l^{FB}(1 - \mu) - 2\beta A(1 - \mu)$ .

At  $\bar{\beta}$ , that derivative is negative if  $A \geq \frac{\pi_l^{FB}}{2\bar{\beta}}$  and stays negative as  $\beta$  increases. So if  $A \geq \frac{\pi_l^{FB}}{2\bar{\beta}}$ , then  $\beta^* \leq \bar{\beta}$ .

At  $\beta = 1$ , that derivative is positive if  $A \leq \frac{\pi_l^{FB}}{2}$ , and stays positive for all smaller values of  $\beta$ .

In between, the derivative is initially positive, then negative, so we find the optimal value at  $\beta^* = \frac{\pi_l^{FB}}{2A}$ . So, if  $\frac{\pi_l^{FB}}{2} \leq A \leq \frac{\pi_l^{FB}}{2\bar{\beta}}$  then  $\bar{\beta} \leq \beta^* \leq 1$ , with  $\beta^* = \frac{\pi_l^{FB}}{2A}$ . ■

## 4 Analysis and Implications

This section presents the results of the sensitivity of optimal registrations and profits to the change in parameters and analyses the welfare effects from the introduction of UBI.

### 4.1 Sensitivity Analysis

We verify the sensitivity of optimal registrations,  $\beta^*$ , and profits,  $\Pi$ , to changes in parameters used in our model. An increase in the initial number of high-types,  $\mu$ , leads to a fall in  $\beta^*$  as the insurance company is already extracting more money from the high-type, and there is less incentive for the company to offer UBI and differentiate the low and high-types. The profit for the company rises as high-types are more profitable. An increase in loss incurred (L) or decrease in initial wealth (W), makes the average profit made on asymmetric information market proportionally higher than the profit made from the first-best contracts offered by installing UBI. Therefore, the company diverts its attention from UBI to the traditional market, leading to a fall in  $\beta^*$  and a rise in profits.

If the probability of accident for high-type,  $\delta$ , rises, it would be more effective to

separate high and low-types by offering the device, leading to a higher  $\beta^*$  and a lower level of profits because it becomes tougher to satisfy the incentive compatibility constraint, as the high-types can benefit by mimicking low-types, at a heavy cost for the insurance company. The opposite holds true if the probability of loss for a low-type,  $\alpha$ , falls. An increase in privacy costs,  $A$ , would make it more expensive for the insurance company to offer UBI, as it needs to offer higher rebates to induce low-types to register for the device. This has a negative impact on profits. The results from the analysis are summarised in Table 1.

| Parameters | $\beta^*$ | $\pi$ |
|------------|-----------|-------|
| $\mu$      | -         | +     |
| $W$        | +         | -     |
| $L$        | -         | +     |
| $\delta$   | +         | -     |
| $\alpha$   | -         | +     |
| $A$        | -         | -     |

Table 1: Results for sensitivity analysis

## 4.2 Welfare Analysis

The introduction of UBI has effects on welfare, creating both winners and losers. The high-type drivers are weakly worse-off as they are charged a premium at least as large for the same full coverage, after a UBI contract is offered to low-types. In monetary terms, the effect of UBI on high-types is  $p_h^{SB}(\beta^*) - p_h(0) \leq 0$  i.e. before UBI was introduced, they paid  $p_h^{SB}(0)$ , while after UBI they pay  $p_h^{SB}(\beta^*)$ . But, the higher premium charged to them gets transferred to the insurance company, and hence this is a zero-sum game. The low-types who do not register for UBI are not affected by UBI, as they receive a lower coverage at a lower premium, but their participation constraint still is binding. The utility they receive before and after the contract remains the

same. The low-types who register for the device now receive full coverage, but pay a higher premium. In absence of a rebate, the participation constraint for low-types would be binding. Hence, the benefit from registering for them comes from the rebate being offered. More precisely, in monetary terms, the effect of UBI on low-types who register is  $R - a_i$ . Given the uniform distribution of privacy costs and the fact that agents in  $[0, R]$  register, the gain to the average UBI subscriber is then  $\frac{R}{2}$ . Since,  $R = \beta^* A$ , we can express the gain as  $\beta^* \frac{A}{2}$ . The insurance company is better-off as it can offer first-best contracts to low-types who register at a higher premium and extract a higher premium from high-type agents as well. In the original problem, the profit function for the company was:

$$\Pi^{SB} = [\mu[p_h^{SB}(0) - \delta L] + (1 - \mu)\pi_l^{SB}(0)].$$

After UBI, the profit function becomes:

$$\mu[p_h^{SB}(\beta^*) - \delta L] + (1 - \mu)\beta^*[\pi_l^{FB} - R] + (1 - \mu)(1 - \beta^*)\pi_l^{SB}(\beta^*).$$

The change in profit function can be expressed as:

$$\Delta\Pi = \mu[p_h^{SB}(\beta^*) - p_h^{SB}(0)] + (1 - \mu)\beta^*[\pi_l^{FB} - R - \pi_l^{SB}(0)] + (1 - \mu)(1 - \beta^*)[\pi_l^{SB}(\beta^*) - \pi_l^{SB}(0)].$$

With UBI, the high-types pay a (weakly) higher premium for the same coverage which increases profits. Among the low-types, less profit is made from those who do not register but more profits are made on those who register. Overall, the change in profit after UBI is positive for the company, as it could always recover its initial profit by choosing  $\beta = 0$ . Combining with the change for consumers, the change in welfare is:

$$\Delta\mathcal{W} = (1 - \mu)(1 - \beta^*)[\pi_l^{SB}(\beta^*) - \pi_l^{SB}(0)] + (1 - \mu)\beta^*[\pi_l^{FB} - \pi_l^{SB}(0) - \frac{\beta^* A}{2}].$$

The first-term is non-positive as low-type agents who do not register see their premium and coverage (weakly) decrease leading to lower profits for the company. The sign of the second term is unknown. Hence, the effect on welfare is in general undetermined.

For the example we have examined in this paper, the effect of welfare on UBI is negative. To illustrate this scenario, we analyse Table 2. As we can see from the table at  $\beta^* = 0.163$ , the company earns an additional profit of \$14.20. However, the overall welfare effect is  $-45.77$  following the introduction of UBI.

| Market Participants           | Effect on consumer surplus | Effect on profit |
|-------------------------------|----------------------------|------------------|
| High-types                    | -70.55                     | +70.55           |
| Low-types who register        | +10.63                     | +8.37            |
| Low-types who do not register | No effect                  | -64.77           |

Table 2: Effect of UBI on market participants when market hasn't collapsed

When we start with a market when the company is serving both high and low-types, the introduction of UBI might not improve welfare as we saw from the results presented in the above table. The company is able to extract more profits by charging higher premiums to high-types and the low-types who register. But it also has to pay a rebate to the low-type who register. Since the company faces a trade-off between making more profits from contracts to high-types and low-types (who do not register), because the introduction of UBI increases the proportion of high-types among unregistered clients, it moves to increase its profits on high-types. The company charges more for full coverage to high-types and offers less coverage to low-types. Since, high-type contracts are a zero-sum game, the losses of profits on low-types who do not register are not compensated by the welfare and profit gain from the introduction of UBI.

To observe a case where the effect on welfare is positive, we take the initial value

of proportion of high-types,  $\mu$ , to be 0.40. Since,  $0.40 > \bar{\theta}$ , this implies that the insurance company is not serving the low-types initially, as it is profitable to serve only the high-types. However, if the company introduces UBI, it will begin to serve the low-types who register. The optimal number of registrations in this case is 0.41. The gains for market participants are as presented in Table 3.

| Market Participants           | Effect on consumer surplus | Effect on profit |
|-------------------------------|----------------------------|------------------|
| High-types                    | No effect                  | No effect        |
| Low-types who register        | +50.43                     | +149.90          |
| Low-types who do not register | No effect                  | No effect        |

Table 3: Effect of UBI on market participants when market has already collapsed

The high-types are unaffected from the introduction of UBI, as the premium charged to them is unchanged. Their participation constraint is still binding and hence that is the maximum premium the company can extract from them. The company benefits from the introduction of UBI as it now serves low-types who register for the device and makes profits on them. As for the low-types who register, they receive first-best insurance as opposed to no insurance coverage before the introduction of UBI. As their participation constraint is binding in both cases, the gains for them are realised from  $R - a_i$ . The low-types who do not register are unaffected, as they do not receive a contract either before or after UBI is introduced. In our example, as shown in Table 3, we obtain a welfare gain as the low-type and the company gain without making the low-type who do not register and the high-types worse-off. UBI is in that case not only welfare-improving but also Pareto improving. This is a general result and we have the following lemma:

**Lemma 1** *If  $\mu \geq \bar{\theta}$ , the introduction of UBI is always Pareto improving.*

The introduction of UBI in a case where the low-types were not being served initially ( $\mu \geq \bar{\theta}$ ), as it was more profitable to extract higher premium from the high-types and

not serve the low-types at all, is always Pareto-improving. This is because it allows the company to offer first-best contracts to the low-types who sign up for UBI, which increases its profits. This result is similar to the use of 3<sup>rd</sup> degree price-discrimination to serve new clients.

### 4.3 Policy Implications

As we saw from our analyses, the introduction of UBI is not always welfare-improving. It could then be a debate whether to ban UBI if it decreases welfare in some cases. A tightening in regulations regarding privacy would lead to a fall in the range of privacy costs, would lead to a higher number of registrations for the device, and consequently higher profits for the company as it now has to provide less rebates to the agents.

As seen in the automobile insurance market, the high-types are penalised when we introduce UBI. Many health insurance companies are using devices like Apple watches to monitor the well-being of people. While in the case of automobile insurance it seems acceptable for the high-types to pay more, as they were being subsidised by low-types before the introduction of UBI, in health insurance this might be more problematic. While it could be justified to charge high-types a higher premium if their condition is due to their lifestyle, it would be unjust if it is due to genetics. Thus, we should be careful to consider the characteristics of each market before concluding on the welfare effects of UBI-like devices in markets other than automobile insurance.

## 5 Conclusions and Extensions

Here we summarise findings from our analyses and explain future fields of research pertaining to this study.

## 5.1 Conclusions

Recent growth in the number of insurance companies offering usage-based insurance led us to study the impact of UBI on market participants. We analysed how introducing UBI would alter the contracts being offered to the low-type and high-type drivers. Keeping in mind that agents have privacy costs associated with installing a device that would lead the insurance companies to observe their driving behaviour, we developed a model to analyse the market. As we saw in previous sections, the introduction of UBI enables the company to offer first-best contracts to low-type drivers who register for the device. The high-types then pay a premium at least as large for the full coverage they keep receiving, and low-types who do not register get lower coverage for lower premium. If the market for the low-types has not collapsed, UBI might lead to a decrease in overall welfare as the new optimal policies imply a transfer from high-types to the company, obtained by reducing the coverage and premium offered to the low-types who do not register for UBI. There is a high probability that the higher profits and the gains made by the low-types with UBI (rebate minus privacy cost) will not compensate for these losses. Interestingly, if we begin with a situation where the low-type market had already collapsed, in which the company was serving only the high-types, the introduction of UBI will generate a Pareto-improvement. Like for the 3<sup>rd</sup> degree price-discrimination, if UBI allows to offer coverage to previously unserved clients, it always increases welfare. Otherwise, it is an empirical question.

## 5.2 Extensions

In this paper we assumed that installing UBI would not change the behaviour of the driver, i.e. a high risk agent would not install UBI as it would reveal her type. However, it might be possible that high-types change their driving behaviour after opting for UBI if the reduction in premium is substantial. In this case UBI would



reduce the probability of incurring an accident if the type of the driver changes from being a high-type driver to a low-type driver, increasing greatly the probability that UBI is welfare-improving.

Another field of future study would be to have more than two types of drivers. We could have multiple types of agents varying in their driving behaviour, and analyse the impact of the introduction of usage-based insurance on each type of agent. Supposing we divide the population of drivers into three types: low, medium and high-types, the effect of UBI on the low and high-types would be similar to our model. The effect on the welfare of medium-types is however not clear, as they are in a dilemma between distinguishing themselves from the high-types or trying to mimick the low-types.

The model could also be extended such that agents with different probabilities of accident face different amount of losses incurred in the case of an accident i.e. we could have a probability distribution instead of discrete events. Even though this would be more realistic, it would complicate the model but the main insights of our model should still hold.

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